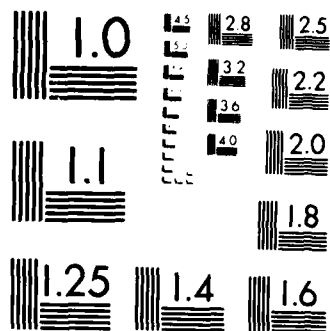


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US Army Corps
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RELIABILITY REPORT FOR COMMUNICATION NETWORKS

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RELIABILITY REPORT FOR COMMUNICATION NETWORKS

JULY, 1984

PREPARED FOR:

U.S. ARMY ENGINEERING DIVISION
HUNTSVILLE, ALABAMA

PREPARED BY:

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1.0 INTRODUCTION

Reliability is defined as the "probability that a component part, equipment, or system will satisfactorily perform its intended function under given circumstances, such as environmental conditions, limitations as to operating time, and frequency and thoroughness of maintenance for a specific period of time."¹

This probability continues to be a major concern in communications oriented systems. Because data communications equipment will fail, users should know failed equipment will affect network operations. Network failure may be one or more terminals out of service; however, network performance may be inhibited to the point of a complete system shutdown. Questions emerge when considering reliability:

- a. How to estimate system availability, in terms of total number of hours per month that terminals can communicate, in order to judge the overall performance and adequacy of a network's design, product construction, and maintenance?

¹ From McGraw-Hill, Dictionary of Scientific and Technical Terms, c 1978, pg. 1349.

- b. What are the chances that a terminal when needed will not be available to run a job?
- c. What is the probability that a project of lengthy run, such as a remote-job-entry task, can be completed without being interrupted by a failure at any point in the terminal-to-computer link?
- d. Will adding redundant equipment in strategic places change reliability and improve system availability? If so, does improvement justify the cost of redundancy?

The search for high reliability must consider the following:

- a. Satisfactory network performance;
- b. Minimum capital investment;
- c. Improved network configuration;
- d. Selection of reliable equipment;
- e. Reduced maintenance cost.

Within the context of systems in general, including data networks, reliability is defined as the probability that no failure will occur within a given time period. Conversely, unreliability is the probability of failure within a given time period. One measure of the reliability of the devised system can be evaluated in terms of the mean time between failures, or MTBF. The answer to the question on terminal availability requires the introduction of the concept of mean time to repair (MTTR) or more specifically, an average MTTR, embracing all devices in the link. When the device fails, some time will pass before it can be repaired and restored to service. The longer the MTTR, the lower the availability of the terminal to the user. The MTTR is obtained from operating experience, and each device in a series link will have its own MTTR value.

These views of reliability must consider the following assumptions:

- a. Equipment "burn-in" and software debugging has been completed before the operating time period (MTBF) begins.
- b. The operating time period of interest never extends beyond the useful life of the equipment or system.

- c. Equipment failures occur at random.
- d. The number of system failures in a given time period is the same for all equally long periods.
- e. The equipment operates in a reasonable, specified environment in a specified manner.

The MTTR and MTBF parameters are available from most central equipment suppliers on a unit-by-unit basis. Other essential parts of the system, such as the Data Transmission Media (DTM), can vary greatly and will be site dependent.

The system availability can be considered the probability of the system working at any given time. It is the percentage of the actual working system time. This percentage is obtained from the MTBF and MTTR. Availability can be calculated for one component, a part of the system (two or more components), or the entire system. However, the respective MTBF and MTTR must be known.

2.0 THE DESIGN CONSTANTS

The constants of the application must be gauged before considering any of the numerous possible network arrangements. This procedure is necessary for obtaining estimates of the following business application parameters:

- a. Number and locations of the processing sites;
- b. Number and locations of the remote terminals;
- c. Information flow patterns between the terminals and processing sites;
- d. Types and transactions to be processed;
- e. Traffic volumes for the transaction types, which may depend on the type of network configuration employed;
- f. Urgency of the information to be transmitted (when must the response be supplied to the remote station, or how soon is the data file required at the destination?);

- g. Capacity reserved for traffic growth;
- h. Acceptable undetected information error rates (bit or block);
- i. Available financial resources;
- j. Reliability and availability requirements.

The geography and performance requirements of the network must be defined by these factors before any major equipment decisions are made. Geographical separations of sources and sinks, and urgency requirements of the messages are the primary basis for data communication network usage. A source and sink are generalized terminal devices, programs, or data files which serve as points of origination and destination, respectively.

2.1 NETWORK TOPOLOGY

In communications trades, a network is defined as a number of radio or television broadcasts stations connected by coaxial cable, radio, or wire lines, so that all stations can broadcast the same programs simultaneously. Local area networks (LANs) are usually

described as privately owned networks that offer reliable, high-speed communication channels, optimized for connecting information processing equipment in a limited geographic area - such as an office, building, complex of buildings, campus, and the like.

LANs are unique, because they can be designed with many technological variations arranged in many different configurations. Local area networks are best defined in terms of the services they provide, and applications they make possible.

A network topology is created by the geometric arrangement of the links and nodes that make up a network. A link (which is also termed a line, channel, or circuit) is a communications path between two nodes. A node is generally defined as a terminal in an electrical network that is common to more than two elements or parts of elements of the networks. The hardware and software chosen for a particular node is determined by the functioning action in the network.

Physical and Logical Links

A combination of physical and logical connections is the basis for node communication. Electro-mechanical

circuits between nodes (permanent or temporary) constitute these physical connections. A logical connection infers that two nodes can communicate, regardless of the direct physical connection. Figure 1 displays physical connections between A-B, A-D, C-D, C-B, E-C, and E-D. E can not communicate with A or B. Node A could communicate with E, however, if these nodes have the ability for routing - or, passing a message along to an adjacent node.

Point-To-Point and Multipoint Links

Two types of links exist as the building blocks of network topologies.

A circuit which connects two, and only two nodes without passing through an intermediate node represents a point-to-point link. Figure 1 and Figure 2 display various configurations of these point-to-point lines. Figure 3 displays an example of a network which is becoming increasingly complex and expensive as full connection is sought.

Figure 4 shows an example of how point-to-point links can be simplified; however, routing decisions must now be made when messages are passed on to other nodes, as

its serial organization. Failure of a new node or of an active component (such as a repeater), adding a new node, or any other break in the ring configuration will cause the network to stop functioning in most cases. Steps can be taken to allow bypass of failure points in distributed rings, although this usually increases the complexity of the repeater at each node, as well as the component cost. Failure of the control node in a centrally controlled ring would inevitably lead to network failure as well.

2.4 BUS NETWORKS

The bus topology functions similarly as a multipoint line - in other words, a single point which is shared by a number of nodes. Refer to Figure 11, Bus Network.

As previously discussed, a star network has all nodes fully connected with point-to-point links, and are joined at a single point or central switch. A ring network consists of separate point-to-point links that are fully connected in a circular arrangement. In contrast to these type of topologies, bus nodes share one physical channel, be it cable taps or connectors. The bus network thus creates a fully connected shared channel.

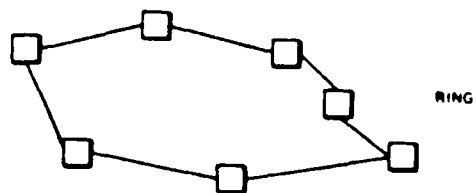


FIGURE 10A - RING NETWORK

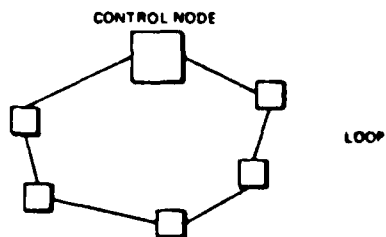


FIGURE 10B - RING (LOOP) NETWORK

Ring networks with centralized control are often referred to as "loops" (See Figure 10B for a common configuration). One of the nodes (the control node) attached to the network controls the access to and communication over the channel by the other nodes. Once permission is given by the control node to transmit a message, the communication can travel around the ring to its destination without further intervention by the control node.

Another loop design has all message exchanges through the central node. In this scheme, the loop network resembles the star network.

The following are considerations for ring network configurations:

- a. Rings must be physically arranged so that they are fully connected.
- b. Lines have to be placed between any new node and its two adjacent nodes each time an addition is made.

The major disadvantage of a loop is reliability. It is very vulnerable to failure of the interfaces because of

ring. Two basic conditions must be met for each node in this type of configuration:

- a. Each node must be able to detect its own addresses.
- b. Each node must be able serve as its own active repeater, retransmitting messages to addressed other nodes.

Retransmission of messages can make ring nodes more or less complex, dependent upon their application, since messages automatically travel to the next node on the ring.

When ring configurations are used to distribute and control local networks, access and allocation methods must be utilized to avoid opposing demands for the share channel. One method involves circulating a bit pattern, termed a token, around the ring. When a node seizes the token, it gains exclusive access to the channel. When the node is finished transmitting, it passes the right to access (i.e., the token) on to the other nodes. Rings thus provide a common network channel, with all nodes being logically connected. Under distributed control, each node under its own initiative, can communicate directly with all of the nodes.

sending node to its requested destination node. The switch may give a "circuits busy" signal to the node requesting to send. When the available part(s) of the destination node are being utilized, the switch may issue a "station busy" signal to the sending node.

There exists a major drawback to star network configuration. Obviously, the central node remains the focal point of this network. All of the system will go down if and when the central node goes down. Thus, the need for redundancy and reliability are self-evident points of interest.

Time-sharing applications, with the central node serving as time-sharing host, constitute a major, utilized form of the star network. Quite common is the PBX (private branch exchange) telephone network. The star network also manifests itself in small-clutered networks, like word processing groups.

2.3 RING ARCHITECTURE

Ring topologies are typified with point-to-point links and continuous unbroken circular configurations. Transmitted messages travel from node-to-node around the

b. Between the outlying nodes;

c. and from all nodes to remote points.

Consequently, outlying nodes are relieved of control functions.

Central and outlying nodes are thus connected with point-to-point lines. This type of configuration forms a low-cost, simpler connection to the central node. This type of star network configuration is ideal for communication between the central and outlying nodes. However, if traffic is heavy between the outlying nodes, the central node may be unduly taxed.

The star network can be constructed in another form, utilizing the outlying nodes as the controlling node. In this scheme, one outlying node may exercise all control, or control may be spread generally between all nodes. Regardless, the central node control is minimized, and it serves as a switch to establish circuits between the outlying nodes.

With distributed control, a method is necessary for solving conflicting requests for connections between nodes. Circuits may not be available to connect the

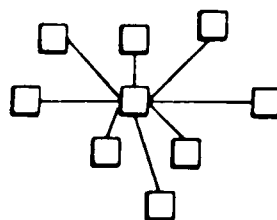


FIGURE 9 - STAR NETWORK

- a. Delays in communications, due to nodes which make routing decisions, performing more network-related functions than what is desirable for LAN nodes. These delays thus result in more overhead.
- b. By making only the necessary node connections, deficiencies and savings gained are not as applicable to local area networks.

The following topologies allow more effective, uniform implementation of network control strategies. They are ring, bus, and star networks.

2.2 STAR NETWORKS

The distinguishing characteristics of this type of topology is that all nodes are joined at a single point, as illustrated in Figure 9. Control is maintained in basically one of three ways. Frequently, star configurations are utilized for networks in which network control is located in a central node or switch. All routing of network message traffic is done by the central node:

- a. From the central to outlying nodes;

Alternately, control can also be distributed so that each node can utilize the line for transmission when the line is free of "message traffic". This type of mechanism is organized with a set of rules implemented in each node. Refer to Figure 7.

Unconstrained Topologies

Unconstrained topologies are also termed hybrid or mesh network configurations. These configurations are of a general nature, and the actual connections made will determine the configurations shape. The variations from one implementation to another can be significant.

Network economics usually determine the connections. Efficiency is best achieved by selecting only the necessary connections.

Combinations of point-to-point and multipoint links utilizing routing and non-routing nodes are good examples of unconstrained topologies. These types are well-suited, and commonly used for long haul, packet-switch networks. Undesirable characteristics do exist; they include.

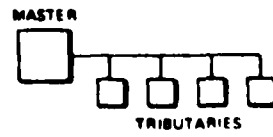


FIGURE 6 - CENTRALIZED CONTROL

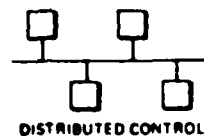


FIGURE 7 - DISTRIBUTED CONTROL

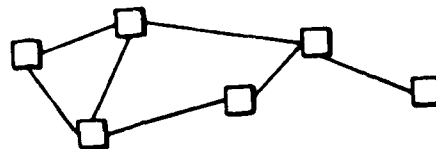


FIGURE 8 - UNCONSTRAINED TOPOLOGY

An example of this type of node is a dedicated communications processor or switch.

With distributed control nodes:

- a. Establish connections; or
- b. Access the network channel independently.

In some instances, all nodes have an equal chance to utilize the network to communicate.

Figure 6 displays an example of centralized control. A master node centralizes control of the multipoint line. The other nodes which utilize the line are termed tributaries, and they are controlled by the master node. All messages to, from, and between these nodes must pass through the master. Each node is queried in the order specified by an internal list to determine who will transmit. Which node receives is determined by selecting each node through its address.

well as recognizing and accepting messages addressed to themselves. The latter is also retained in this routing process. In Figure 4 intervening nodes must now be employed. Figure 5 displays a multipoint or multidrop link. Basically, this type of link is a single line, which is shared by more than two nodes. Multipoint lines minimize the number of lines required for node connection and line cost. Thus, the six nodes pictured in Figure 5 can communicate by sharing a single multipoint line. Nodes on this type of line are generally more complex than simple point-to-point nodes. They must handle messages based on their addresses, similar to routing nodes. Access to the line must be controlled by some method to avoid usage conflicts, since this line is shared by a number of nodes.

Topology and Channel Control

Network designers must decide if control of a network is to be centralized or distributed. With centralized control, one node controls:

- a. Access to the network; or, which nodes can send messages, and when.
- b. Allocation of the channel (how much of a channel can a node use, and for how long?).

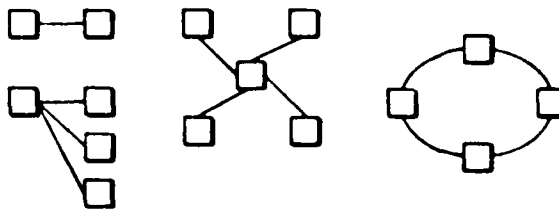


FIGURE 2 - POINT-TO-POINT, VARIOUS DISPLAYS

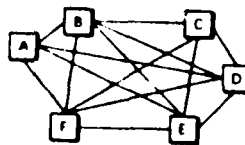


FIGURE 3 - POINT-TO-POINT, COMPLEX

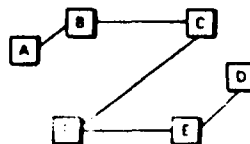


FIGURE 4 - POINT-TO-POINT, ROUTING

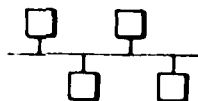


FIGURE 6 - MULTIPOINT OR MULTIDROP LINK

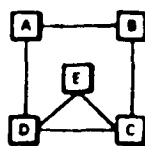


FIGURE 1 - PHYSICAL AND LOGICAL LINKS

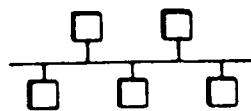


FIGURE 11 - BUS NETWORK

The bus topology, like the ring, has most frequently been used for distributing control on local area networks. Messages placed on the bus are broadcast out to all networks, and are able to recognize their own addresses in order to receive transmission. However, unlike nodes in a ring, they do not have to repeat and forward messages intended for other nodes. As a result, there is none of the delay and overhead associated with retransmitting messages at each intervening node, and nodes are relieved of network control responsibility at this level.

One distinct advantage of this type of network architecture is high reliability. Network operation will discontinue in the event of node failures, due to the passive role nodes play in transmission on the bus. Distributive bus networks are thus inherently resistant to single point failures. Other advantages include easy configuration and expansion in most physical layouts (room, building, or building complex).

Centrally controlled bus topologies are possible, but are not common, for LANs. They would resemble a multi-point line with a master and tributary nodes. As in all cases of centralized control, the master node would

communicate in one of the most attractive features of the bus topology and local area networks.

There are several considerations for the design of bus networks. Components, such as transmitters/receivers, must be designed for reliable and maintainable operation. Also, owing to the potential difficulty in locating faults on a bus, network management capability or test equipment must allow fault detection and isolation to facilitate repair and maintenance.

2.5 NETWORK REDUNDANCY

Redundancy is defined as "any deliberate duplication or partial duplication of circuitry or partial duplication of circuits or information systems on communication failure."² Redundancy is an effective approach to dramatically increase the reliability of a system or network. The provision and maintenance of equipment represents the cost factor. However, hardware costs continue to decrease - consequently, this is becoming a progressively less important factor, particularly in relation to the losses incurred whenever the system is

² Ibid, p. 1339

inoperable. The redundant equipment also provides added capability, the attendant reduction in sparing requirements, and the relaxation of maintenance response time requirements. All of these factors can be realized with redundant systems, thereby reducing maintenance costs.

In the final analysis, redundancy may be considered a viable alternative to meeting reliability requirements. The following are factors which should be considered and evaluated:

- a. Reliability should be significantly increased. If a unit's MTBF is substantially greater than that of another non-redundant system element, there is no advantage to duplicating the unit.
- b. The practicality of the unit should be evaluated. Problems may arise with incorporating a second unit in the system, additional multiplexing may be required, or switching hardware may be so unreliable that little gain is realized.
- c. Redundancy should be cost-effective. The cost of providing redundancy should be weighed against its benefits. If no specific reliability requirement exists beyond a desire that it could be maximized

without significantly adding to the cost of the system, then consideration should be given to duplicating only those low MTBF units which are also relatively low in cost.

3.0 RELIABILITY

Reliability (previously discussed in Section 1) may be mathematically approximated for a device or system as:

$$R(t) = e^{-\lambda t}$$

Here, e denotes the base of the natural logarithm (2.7183), λ is a constant termed the average failure rate, and t is the time instant for which the device reliability is desired.

A more convenient form of this equation is:

$$R(t) = \exp(-\lambda t) \quad (1)$$

Here, \exp stands for exponential. The constant for the average failure rate, λ , is:

$$\lambda = 1/(\text{MTBF}) \quad (2)$$

Thus, Equation 1 states that as MTBF increases, the probability of failure decreases, and the average duration of failure-free operation increases.

Sample calculation: What is the probability that a device will not fail in 500 hours when its MTBF, as determined from operating experience, is 1,000 hours?

Because the device fails on the average once every 1,000 hours, λ is 1/1,000. Using Equation 1 with $t = 500$, then:

$$R(t) = \exp(-500/1,000) = 0.607$$

Values of the exponential expression can be readily determined from exponential tables (Refer to Table 1) or on a scientific calculator, or (without too much precision), from the graphs in Figure 12.

The interpretation of the value 0.607 is that there is a slightly better than 60% chance that the previously mentioned device with an MTBF of 1,000 hours will run for 500 consecutive hours without a failure - with the 500 hours starting at any arbitrary instant. Conversely, there is approximately a 40% probability the device will experience a failure during an arbitrary time period of 500 consecutive hours.

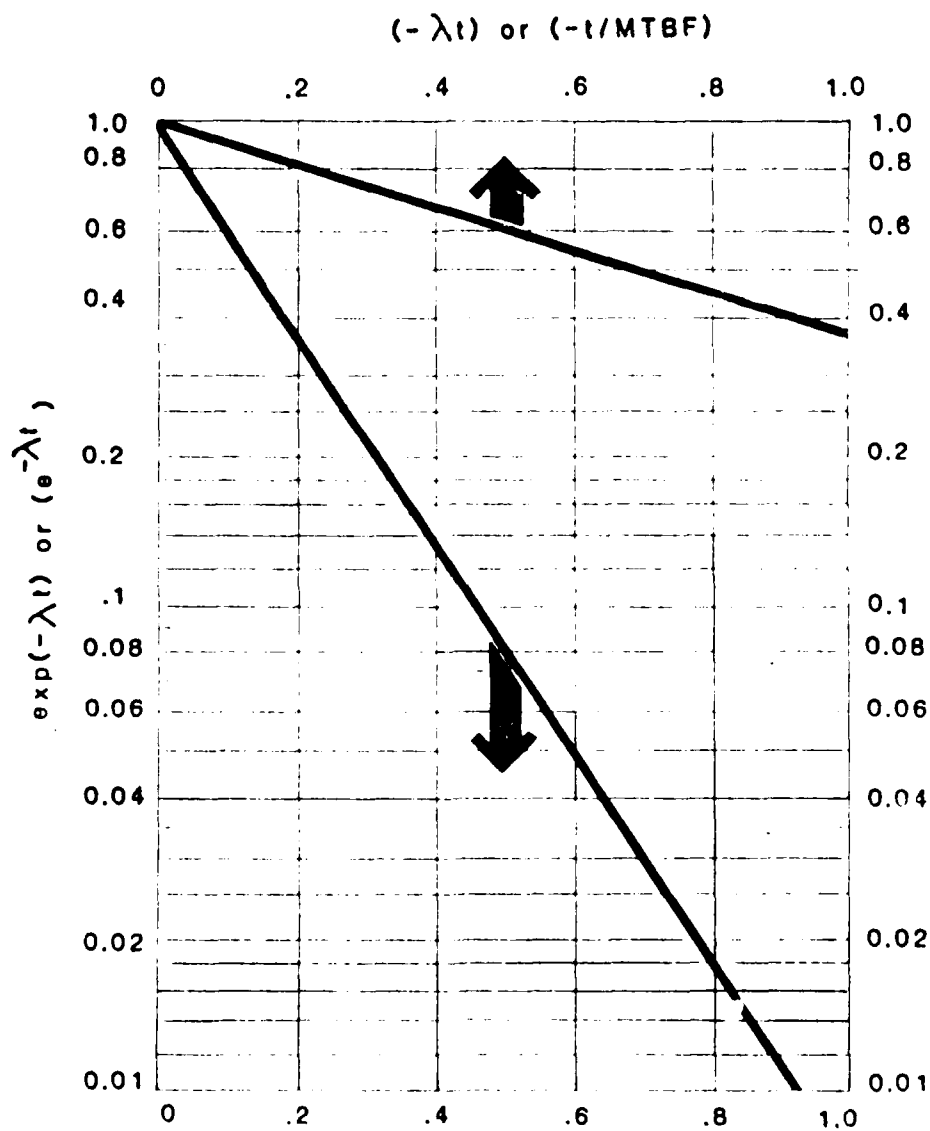


FIGURE 12 - RELIABILITY FINDER

Connection Types

In order to effectively judge the reliability of an end-to-end link in a typical data communications network (e.g. a remote terminal and a host computer), a link must first be defined as a series, parallel, or series/parallel connection (Figure 13).

A typical series link is shown in Figure 14. It includes every device and line from the remote-job entry (RJE) terminal to the central processing unit (host computer). To find the link's reliability, the equivalent average failure rate of the complete link, λ_1 , must be computed and inserted into Equation 1.

In a series connection, a failure in any device in the link will put the entire connection out of action. That is:

$$R_1 = R_1 \times R_2 \times R_3 \dots R_n \quad (3)$$

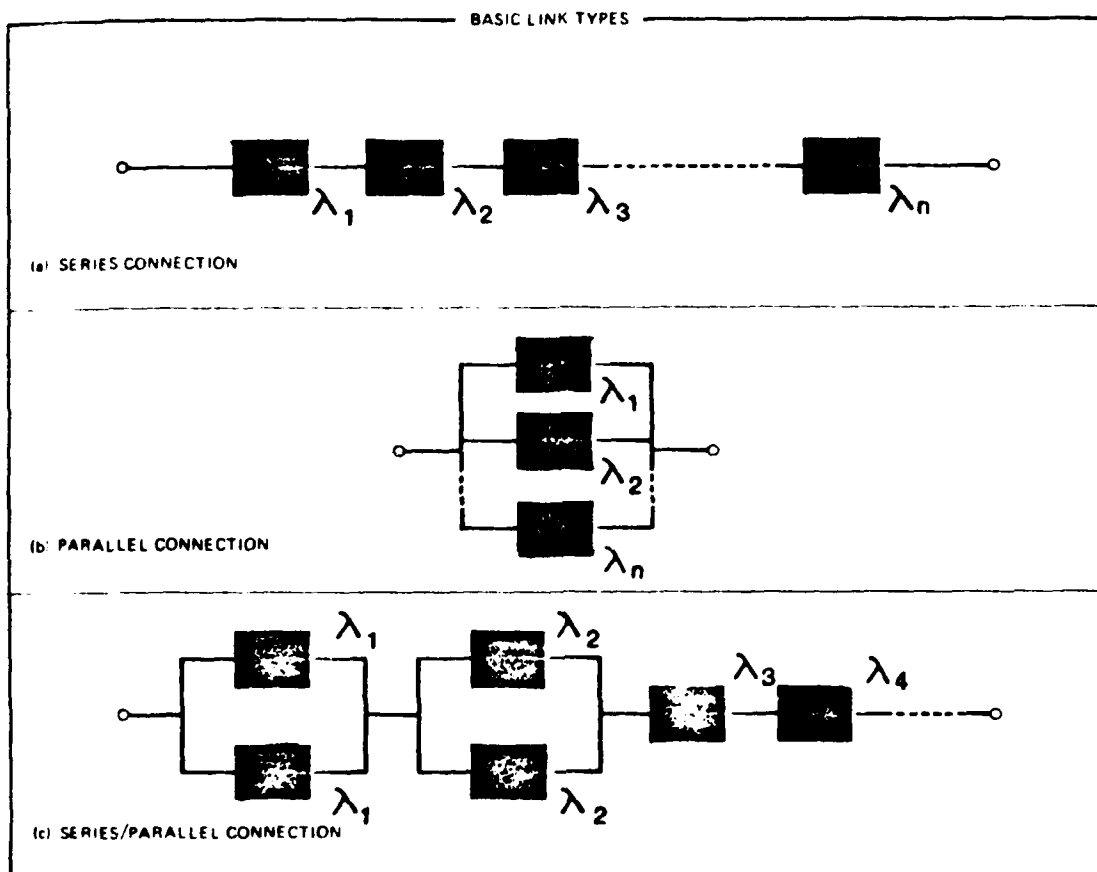


FIGURE 13 - BASIC LINK TYPES

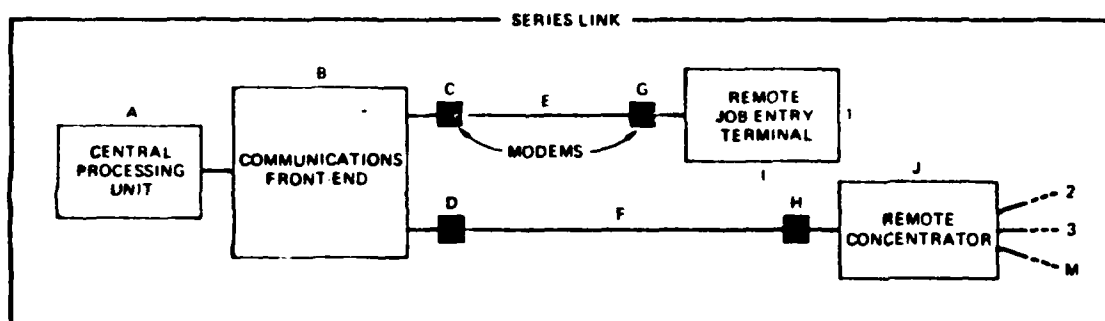


FIGURE 14 - TYPICAL SERIES LINK

where P is link reliability. Furthermore, the equivalent average failure rate of the link is the sum of the failure rates of the individual devices:

$$\lambda_1 = \lambda_1 + \lambda_2 + \lambda_3 + \dots + \lambda_n \quad (4)$$

Therefore:

$$MTBF = 1 / (\lambda_1 + \lambda_2 + \lambda_3 + \dots + \lambda_n) \quad (5)$$

The series link shown in Figure 14 consists of six devices and elements: the RJE terminal (I), the terminal modem (G), the line (E), the central site modem (C), the communications front end (B), and the central processing unit (A). A failure in any of these elements affects the RJE-terminal user (I).

Equation 5 yields the mean time between failures as seen by user 1. That is:

$$MTBF_1 = 1 / (\lambda_1 + \lambda_g + \lambda_e + \lambda_c + \lambda_b + \lambda_a) \quad (6)$$

where

λ_1 = failure rate of the RJE terminal

λ_g = failure rate of the RJE terminal's modem

λ_e = failure rate of the transmission line from the RJE terminal

λ_c = failure rate of the central-site modem serving the RJE terminal

λ_b = failure rate of the communications front
end processor

λ_a = failure rate of the central processing unit

When the hypothetical failure-rate data contained in Table 1 is inserted, the equivalent average failure rate as seen by the RJE-terminal user works out at:

$$\begin{aligned} \text{MTBF}_1 &= 1 / [(1+0.2+2+2+0.2+5+10) \times 10^{-3}] \\ &= 54.3 \text{ hours} \end{aligned}$$

Therefore, the reliability for this link is:

$$R(t) = \exp(-t/\text{MTBF}_1) = \exp(-t/54.3) \quad (7)$$

The equations and calculations to this point can be utilized in determining these important considerations:

- a) What is the probability that the RJE-terminal user can transmit a two-hour job to the host computer without a link failure during that period?
- b) What is the availability of the remote-job entry terminal to the user?

TABLE I		
DEVICE OR SUBSYSTEM	FAILURE RATE (PER 1,000 HOURS OF OPERATION)	MEAN TIME TO REPAIR (HOURS)
REMOTE JOB ENTRY TERMINAL (T)	$\lambda_T = 10$	30
MODEM AT RJE SITE (G)	$\lambda_G = 0.2$	25
LINE TO RJE SITE (E)	$\lambda_E = 20$	40
MODEM AT CENTRAL SITE (C)	$\lambda_C = 0.2$	25
COMMUNICATIONS FRONT END (B)	$\lambda_B = 50$	50
CPU (HARDWARE, SOFTWARE) (A)	$\lambda_A = 100$	20

the need for human involvement in the tedious tasks of network troubleshooting. Included in these diagnostics will be those for analog line impairments, bit-error-rate tests including bit-pattern generators, and protocol tests.

Diagnostics Help

The only real options open to designers who want to increase system availability are to select reliable equipment in the first place and to install redundant equipment and lines wherever the improvement in network availability outweighs the penalty of extra cost. Reliability is up to the vendor. That is, only in rare instances will the user work with the vendor to upgrade the reliability of the equipment. However, the user can look into competitive equipment and talk with people who have installed the equipment in which he's interested.

Since system availability, in terms of usable terminals, depends on both the reliability, or MTBF, and the downtime as measured by mean time to repair, or MTTR, users can overcome the consequences of marginal reliability by speeding up fault isolation and diagnosis. This is the reason for the current strong trend toward installing a full range of diagnostic features as an integral part of the data communications network. These diagnostic capabilities have already appeared in hardware form.

In the future greater emphasis will be placed on diagnostic routines driven by software which will minimize

$$P_5 = \exp(-200/200) = 0.368$$

Therefore, the equivalent reliability is:

$$(0.819)(0.670)(0.697)(0.697)(0.368) = 0.0981$$

Thus, there is a slightly less than 10 percent chance that the connection will be sustained without failure in the first 200 hours of operation.

Here, $MTBF_1 = 1,000$, $MTBF_2 = 500$, and $MTBF_5 = 200$ and, from Table 2:

$$MTBF_3 = 3/2 \lambda_3 = 3,000/8 = 375$$

and

$$MTBF_4 = 3/2 \lambda_4 = 3,000/8 = 375$$

Therefore, from Equation 5:

$$MTBF = \frac{1}{\frac{1}{1,000} + \frac{1}{500} + \frac{1}{375} + \frac{1}{375} + \frac{1}{200}} = 75 \text{ hours}$$

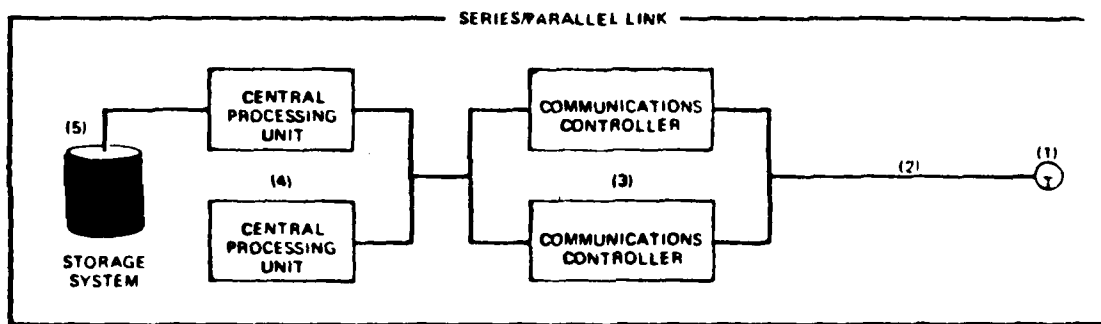


FIGURE 15 - SERIES/PARALLEL

TABLE III			
	DEVICE NUMBER	MTBF (HOURS) (ASSUMED)	FAILURE RATE (FAILS PER 1,000 HOUR)
TERMINAL	1	1,000	1
LINE	2	500	2
COMMUNICATIONS CONTROLLER	3	250	4
CPU	4	250	4
STORAGE SYSTEM	5	200	5

combination. The equations for series connections can be used to determine the reliability and equivalent MTBF for a series/parallel connection (Figure 13C).

Using the hypothetical data contained in Table 3 for the configuration in Figure 15, compute the equivalent MTBF and reliability (R_e) as seen by the user of the terminal, T, for an interval of $t = 200$ hours. Here, treating the configuration as if it were a series connection only and using Equation 3:

$$R_e = R_1 \times R_2 \times R_3 \times R_4 \times R_5$$

where R_1 is terminal reliability, R_2 is line reliability, R_3 the reliability of the parallel controllers, R_4 the reliability of the parallel CPUs, and R_5 the storage-system reliability. Thus, at $t = 200$:

$$R_1 = \exp(-200/1,000) = 0.819$$

$$R_2 = \exp(-200/500) = 0.670$$

$$R_3 = 2\exp(-200/250) - \exp(-400/250) = 0.697$$

$$R_4 = 2\exp(-200/250) - \exp(-400/250) = 0.697$$

Of course, the key practical problem for data communications users is their lack of ability to control these MTBF variables for individual devices.

Table 2 contains the equations for the equivalent reliability of several types of parallel configuration. Here, the equivalent subsystem can be treated mathematically as being one element in a series connection, even though the actual equipment is linked in parallel. This table also contains the MTBF of the equivalent subsystem. Thus, for the preceding case, the appropriate equation is $3/2 \lambda_1$ (both communications front ends have the same 500 hour MTBF). Therefore, the net MTBF is:

$$3 \times 500/2 = 750 \text{ hours}$$

That is, even if one communications front end fails at the end of 500 hours and is replaced by the hot standby unit, statistically the combination will last another 250 hours - during which the network remains operational while the failed front end is being repaired.

Series/Parallel Connections

In practice, if redundant equipment is used at all, the actual configuration will be a series/parallel

For $t = 500$ hours, then:

$$R_C = 2 \exp(-1) - \exp(-2) = 0.601$$

It is important to note that since the function R_C is not purely an exponential, the comparison of reliability is only valid for the first 500 hours - not an arbitrary 500 hours.

By comparison, one CPU having an MTBF of 500 hours yields a reliability of:

$$R = \exp(-500/500) = 0.368$$

while one CPU having an MTBF of 1,000 hours has a reliability of:

$$R = \exp(-500/1,000) = \exp(-0.5) = 0.606$$

For the situations discussed here, the redundant-CPU connection definitely improves reliability, but at substantially double the cost. However, taking steps to improve the MTBF of a single CPU from 500 hours to 1,000 hours will probably be less costly and yet will provide the same reliability as a redundant configuration.

Suppose a computer-based communications system uses redundant central processing units, each with an MTBF of 500 hours?

What is the probability that the parallel CPU combination will operate (not fail) for 500 hours?

How does this performance compare with the reliability when using just one CPU? What is the net mean time between failures of the parallel combination?

Using Equation 1:

$$P_1 = \exp(-t/500) \text{ and } R_2 = \exp(-t/500)$$

Therefore:

$$P_1 = 1 - [\exp(-t/500)] \text{ and } P_2 = 1 - [\exp(-t/500)]$$

Hence, using Equation 8:

$$R_c = [1 - \exp(-t/500)] [1 - \exp(-t/500)]$$

$$R_c = 2 \exp(-t/500) - \exp(-2t/500)$$

Here, the reliability of the entire series connection is obtained simply by summing the individual failure rates of each device.

The use of redundant or hot standby devices and lines is particularly common in computer-based data communications systems. Two devices - perhaps two communications front ends-are placed in parallel with each other, but only one device has to be on line for the network to be operational. If the operating unit fails, then the standby unit is promptly placed on line. A diagram of a generalized parallel connection is contained in Figure 13B.

Finding Redundant Reliability

Defining R_C as the probability of the parallel connection not failing and P_C as the probability of the parallel connection failing, then:

$$R_C = 1 - P_C = 1 - [(1 - R_1)(1 - R_2) \dots (1 - R_n)] \quad (8)$$

$$= 1 - (P_1 \times P_2 \times P_3 \dots P_n) \quad (9)$$

NUMBER OF PARALLEL STAGES	RELIABILITY OF EQUIVALENT SUBSYSTEMS	MTBF OF EQUIVALENT SUBSYSTEM
1	$e^{-\lambda t}$	$\frac{1}{\lambda}$
2 EQUAL	$2e^{-\lambda_1 t} - e^{-2\lambda_1 t}$	$\frac{3}{2\lambda_1}$
2 UNEQUAL	$e^{-\lambda_1 t} + e^{-\lambda_2 t} - e^{-(\lambda_1 + \lambda_2)t}$	$\frac{1}{\lambda_1} + \frac{1}{\lambda_2} - \frac{1}{\lambda_1 + \lambda_2}$
n EQUAL	$1 - (1 - e^{-\lambda_1 t})^n$	$\frac{1}{\lambda_1} + \frac{1}{2\lambda_1} + \frac{1}{3\lambda_1} + \dots + \frac{1}{n\lambda_1}$
* λ_1 = FAILURE RATE FOR EACH DEVICE		

which equals 3.1 hours.

Refer to Table 2 and other standard reliability handbooks which define system availability, a , as:

$$a = (MTBF) / (MTBF + MTTR)$$

so that, for the situation in the series-connection numerical example:

$$a = (54.3) / (54.3 + 3.1) = 0.946$$

Consequently, the user of the RJE terminal can be sure that, on average, the terminal will be available for communications with the host computer 946 out of every 1,000 operating hours, and that once the operator starts a two-hour job the run will continue to completion 96% of the attempts.

An alternative and perhaps more direct way of calculating the reliability of a series connection is to use an equivalent relationship derived from Equations 1, 2, 3, and 4A, namely:

$$R(t) = \exp[-\lambda_1 + \lambda_2 + \lambda_3 + \dots \lambda_n)t] \quad (4B)$$

The average value of the MTTR is the sum of the individual devices' MTTRs, with each MTTR multiplied by its own failure probability. That is:

$$\text{AVG MTTR} = (\text{MTTR}_i) (P_i)$$

The sum of the probabilities of failure of the devices in the link must add up to unity. To find the individual failure probabilities requires the mathematical step called normalization.

That is:

$$P_i = \lambda_i / \sum_{i=1}^n \lambda_i$$

Therefore:

$$\text{AVG MTTR} = \frac{(\lambda_1 \text{ MTTR}_1 + \lambda_2 \text{ MTTR}_2 + \dots + \lambda_n \text{ MTTR}_n)}{(\lambda_1 + \lambda_2 + \dots + \lambda_n)}$$

Using the failure-rate and MTTR data contained in Table 1 for the link shown in Figure 14, then average MTTR as seen by the user of the RJE link is:

$$\frac{[(1)(3) + (0.2)(2.5) + (2)(4) + (0.2)(2.5) + (5)(5) + (10)(2)] 10^{-3}}{18.4 \times 10^{-3}}$$

The answer to the first question can be obtained from Equation 7, using $t = 2$ hours:

$$R(t) = \exp (-2/54.3) = 0.9625$$

This interpretation says that 96 out of every 100 two-hour job attempts will be processed without link failure. However, four times out of a hundred, the job will be aborted by an individual failure.

Mean Time To Repair

The answer to the question on terminal availability requires the introduction of the concept of mean time to repair (MTTR) or, more specifically, an average MTTR embracing all the devices in the link. When a device fails, some time will elapse before it can be repaired and restored to service. The longer the MTTR, the lower the availability of the terminal to the user. The MTTR is obtained from operating experience, and each device in a series link will have its own MTTR value. Average MTTR, then, is one value for the link that takes into account all the individual devices' MTTRs.

4.0 CASE STUDY - ACTUAL SYSTEMS

The individual systems to be studied are a dual loop with redundant front end modems versus a radial system with 8 points of connection which are shown in Figures 16 and 17.

The ring type system as described is actually a bus configuration arranged in a loop, since each node has access to two lines. The communication lines are common to all.

The radial system is actually a parallel system, since each node has its own front end modem. Each may be re-configured as shown in Figures 18 and 19.

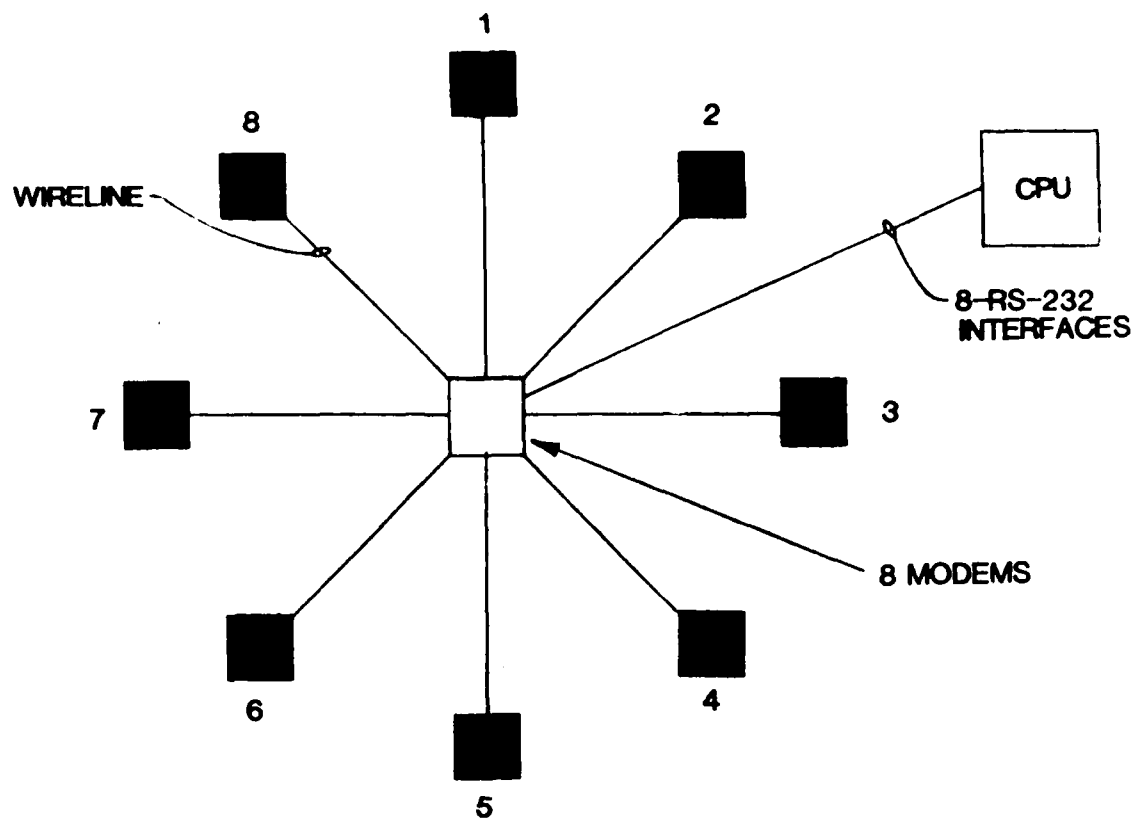


FIGURE 16-RADIAL SYSTEM

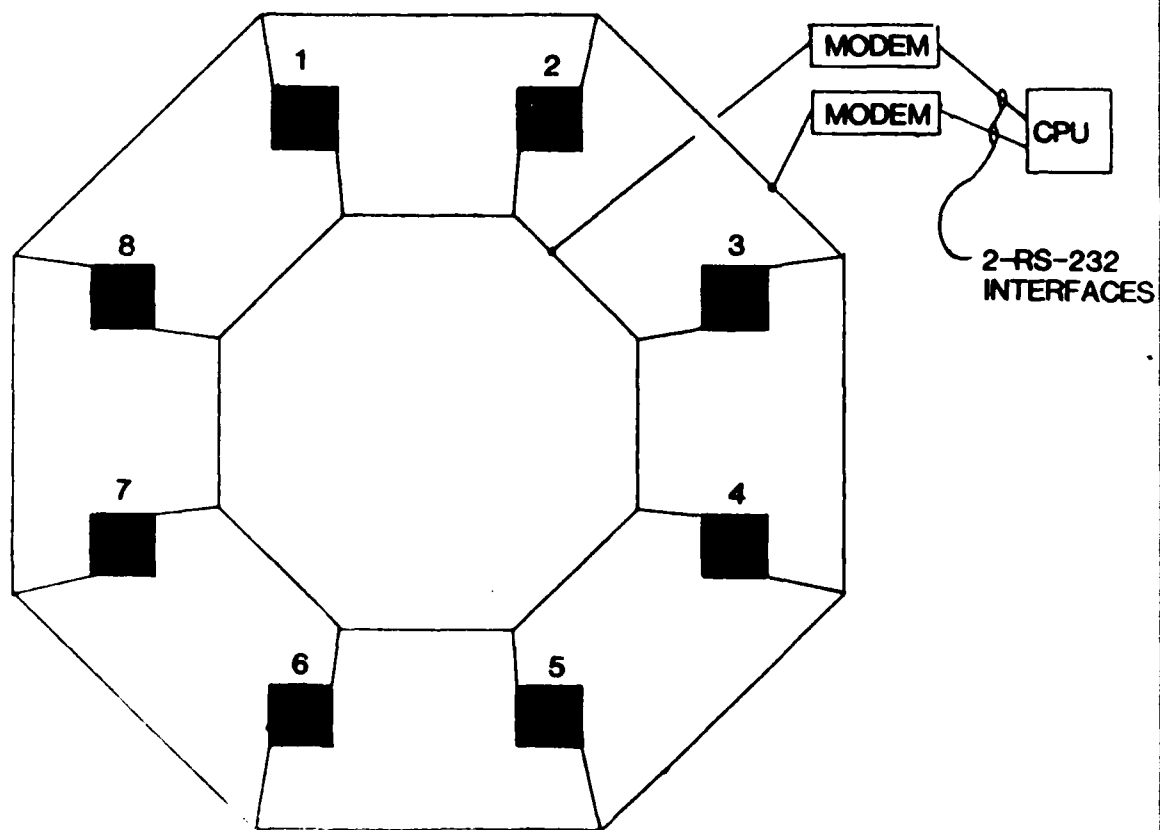


FIGURE 17 - RING SYSTEM

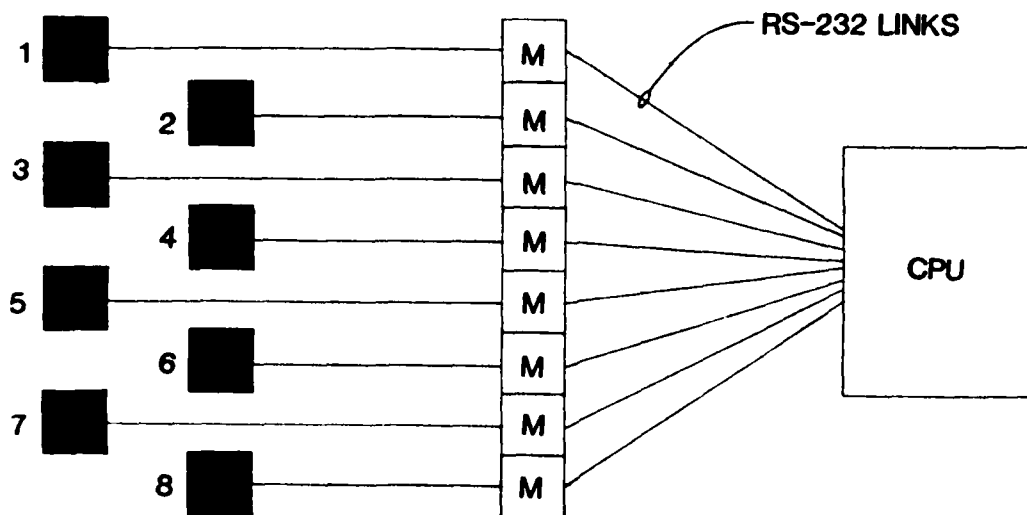


FIGURE 18 -RADIAL SYSTEM

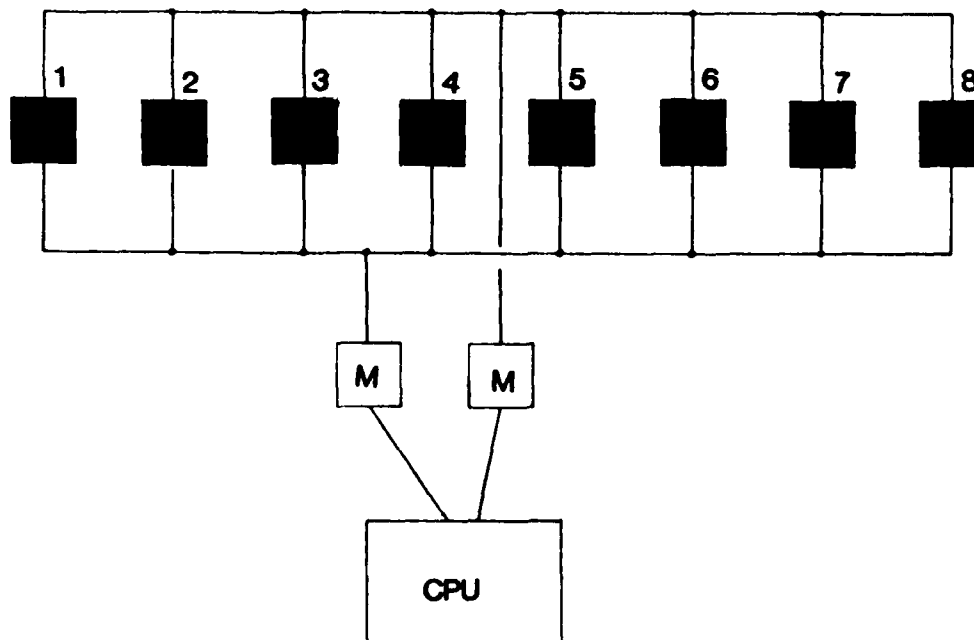


FIGURE 19 -RING SYSTEM

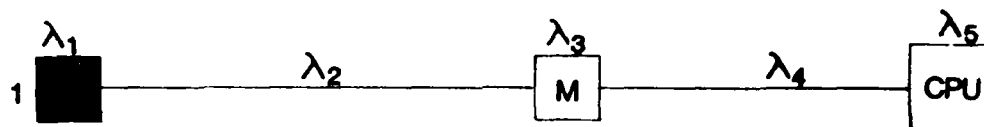


FIGURE 20 - RADIAL LINK POINTS

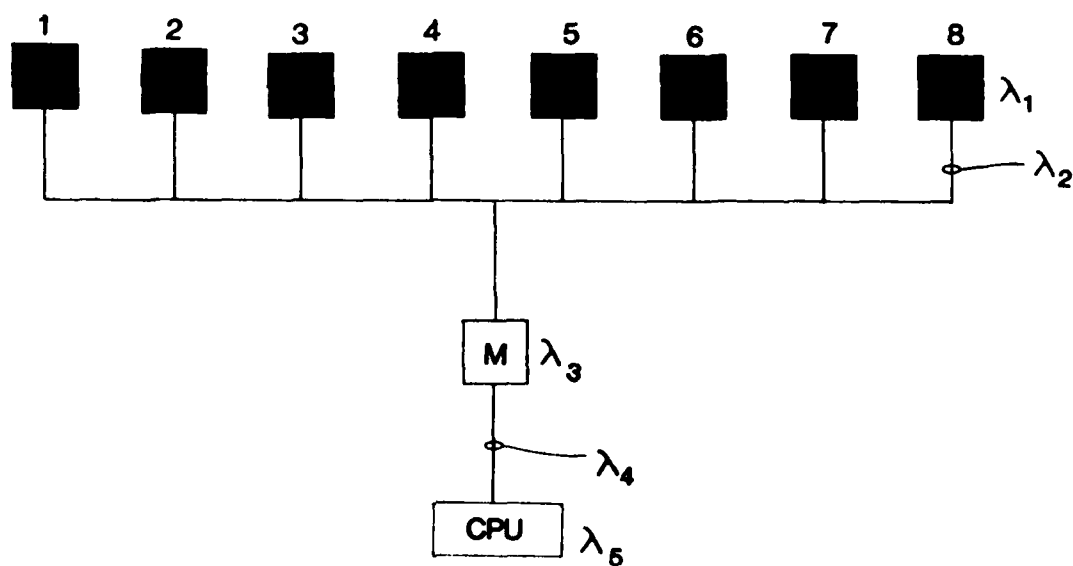


FIGURE 21 - RING LINK POINTS

For the radial or parallel system, each link would have the following points (Refer to Figure 20). The failure rate for the link would be the sum of the failure rates for each individual device:

$$(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)$$

The MTBF would be: $1/(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)$

substituting hours / 1000 hours operation from Table 1:

$$\begin{aligned} \text{MTBF} &= 1/ (.2 + 2.0 + 5.0 + 2.0 + 10.0) = \\ &1/19.2 = .052 \times 10^{-3} = 52.1 \text{ Hrs.} \end{aligned}$$

The reliability for this link would be:

$$R(T) = \exp(-t/52.1) \text{ - for any time period (t);}$$

$$R(200) = \exp (-200/52.1) = .0215 = 2.15 \text{ in 200 hours;}$$

the average MTTR for this configuration would be

$$\frac{(.2)3.0 + (2.0)4.0 + (5.0)5.0 + (2.0)4.0 + (10.0)2.0}{.2 \times 2 \times 5 \times 2 \times 10} = \frac{61.6}{40.0} = 1.54$$

$$\text{the availability would be } \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} = \frac{52.1}{52.1 + 1.54} = .9713$$

Since each link is connected to the CPM through a modem, the reliability of each line would be on availability of 97.13%, with no factor for the other links in the system. The failure of any other link would not affect the operation of the rest of the system.

For the bus system, each line would have the following points (Refer to Figure 21). All nodes are in parallel. The failure rate for each remote unit would be the same as that for a semi-connection, or a radial system as previously outlined. However, since all eight are in parallel on the same bus, a bus failure would cause a system failure. The addition of the second bus in a redundant configuration would give an increased reliability:

$$3/2 \lambda = 3/2 (52.1) = 78.1 \text{ Hours (MTBF)}$$

$$R(T) = \exp (-T/\text{MTBF})$$

$$R(200) = \exp (-200/78.1) = .07724 = 7.7\% \text{ in 200 Hrs}$$

Summary Results are as follows:

Radial System: MTBF = 52.1 Hrs; R(200) = 2.15%

Ring System: MTBF = 78.1 Hrs; R(200) = 7.7%

5.0 CONCLUSIONS

While the numbers indicate that the redundant loop is the more reliable of the two some practical considerations need to be considered.

- A. Both of the loops would probably be installed in the same bundle. A mechanical or lightning-caused problem would affect both loops.
- B. Damage due to mechanical problems almost always causes a short in the cable, thus rendering the entire loop inoperative. An advantage is to isolate the faulted section and allow the loop to feed in both directions. The entire system would be down until the fault was isolated.
- C. A severe lightning strike on one loop would more than likely destroy a large portion of the electronic connection.
- D. The radial system, if all lines are kept separate, would practically eliminate a total system failure. The disadvantage is that the one link that has been damaged would remain out of commission until repaired, with no way to bypass the fault.

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